

Historic, archived document

Do not assume content reflects current scientific knowledge, policies, or practices.

1A7

PP885-1 7312 8

United States
Department of
Agriculture

Agricultural
Research
Service

ARS-10

September 1984

Ethylene and Low-Temperature Treatments of Honeydew Melons To Facilitate Long-Distance Shipping

Lipton, Warner J. and Bruce E. Mackey. 1984. Ethylene and low-temperature treatments of honeydew melons to facilitate long-distance shipment. U.S. Department of Agriculture, Agricultural Research Service ARS-10, 28 p.

The export market for honeydew melons can be maximized only if they have desirable eating quality when they reach the consumer, after 2 to 3 weeks. The same requirement exists for the successful extension of the domestic marketing season. Current practices, in which melons of minimum maturity are shipped without prior treatment with ethylene, sometimes fail to achieve this goal. Thus, we determined whether these melons could be successfully stored at lower than currently recommended temperatures if they were first treated with ethylene. Current recommendations, developed for briefer storage periods, call for temperatures between 7.5° and 10°C (45° and 50°F) to avoid chilling injury. We also measured the rates of carbon dioxide (CO₂) and ethylene production at 30° and 40°C (86° and 104°F).

Honeydew melons were exposed at 20°, 30°, or 40°C (68°, 86°, or 104°F) to 1,000 p/m ethylene for 12, 18, or 24 (20°C only) hr before their storage at 2.5° or 5°C (36° or 41°F) for about 2½ weeks. One set of controls was treated similarly, except that the ethylene treatment was omitted and a second set was immediately placed at 7.5°C (45°F). The melons were evaluated immediately after storage and after holding them an additional 2 or 3 days at 20°C.

The rates of CO₂ and ethylene production were higher at 40°C (104°F) than at 30°C (86°F) and higher at either temperature than rates for 20°C (68°F) reported in the literature. The rate of ripening following the temporary holding at 40°C was about equal to or lower than that following holding at 30°C. Thus, the ripening process seems to be more sensitive to high temperature than to CO₂ or ethylene production.

A desirable aroma developed in about 1½ to 5 times as many ethylene-treated melons as in the controls when storage was at 2.5° or 5°C (36° or 41°F). Aroma development was intermediate in the controls stored at 7.5°C (45°F).

The incidence of wet cavity was only slightly higher in the ethylene-treated than in the control lots.

Chilling injury (CI) virtually was prevented (incidence less than 1 percent) by the ethylene treatments, even when storage was at 2.5°C (36°F), whereas up to 14 percent of the control melons showed moderate or worse CI. No visible CI developed among any melons stored at 5° or 7.5°C (41° or 45°F).

External appearance was not necessarily a good indicator of potential eating quality, since many melons of good or excellent appearance either had not developed any aroma, an important aspect of eating quality, or else they were overripe. After storage and ripening, about half or more of the treated melons, compared with about one-third or fewer of the controls, were of acceptable potential eating quality (rated salable or better in appearance, desirably ripe by external criteria, and a detectable or pleasant aroma). About 40 percent of ethylene-treated melons and about 25 percent of the controls were of optimum potential eating quality after ripening (criteria same as for "acceptable," but appearance good or excellent). A 12-hr exposure to ethylene would be adequate if the melons were between about 30° and 40°C (86° and 104°F), but a 24-hr treatment would be preferable if the melons were at about 20°C (68°F) at the time of treatment, which would be within a few hours of harvest. Gassing with ethylene should be followed by storage or transit between 2.5° and 5°C (36° and 41°F). Such a sequence would only minimally increase the risk of decay over current practices for shippers who historically have had minimal problems with decay during extended marketing of their honeydew melons. This small risk would have to be judged against the considerable advantage of the greater proportion of palatable melons that would reach the consumer.

The need for development of methods for rapid, accurate, and economical maturity sorting of honeydew melons and for effective decay control is discussed.

Keywords: muskmelons, *Cucumis melo*, chilling injury, respiration, ethylene production, ripening, disease, disorders.

Acknowledgments

We thank shippers of honeydew melons for their cooperation in these tests; D. C. Fouse for the gas analyses and S. J. Peterson, Fresno, for the excellence of her assistance. R. F. Kasmire, University of California, Davis; H. M. Couey, USDA, Hilo, Hawaii, and A. E. Watada, USDA, Beltsville, Md., for their helpful review.

Contents

	Page
Introduction	5
Materials and methods	6
General	6
Melons exposed to ethylene at 20°C (68°F)	6
Melons exposed to ethylene at 30° or 40°C (86° or 104°F)	7
Statistical analysis of data	7
Results	8
Rates of carbon dioxide and ethylene production	8
Rate of ripening	8
Degree of ripening	9
Development of aroma	12
Development of wet cavity	12
Defects	14
Decay	16
Corrugations	18
Weight loss	19
Quality of melons	19
Soluble solids content	22
Discussion and conclusions	24
Physiological aspects	24
Separation of honeydew melons by maturity class	24
Literature cited	25

U. S. DEPT OF AGRICULTURE
NATIONAL AGRICULTURAL LIBRARY
RECEIVED

NOV 14 1988

ORDER UNIT
ACQUISITION SECTION

Copies of this publication may be purchased from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161.

ARS has no additional copies for free distribution.

Ethylene and Low-Temperature Treatments of Honeydew Melons to Facilitate Long-Distance Shipment

By Werner J. Lipton and Bruce E. Mackey¹

Introduction

In 1980, American growers produced about 7300 hectares (18,000 acres) of honeydew melons that were valued at about \$42 million. While most of these were marketed in the continental United States, honeydew melons valued at about \$2 million were exported from California to Hong Kong and Japan (5, personal communication, Federal-State Market News Service), with smaller quantities coming from Texas and Arizona. Export markets, especially those in the Far East, probably could be expanded if a higher proportion of high quality melons would reach such distant markets (6, various industry sources, personal communications). Decay, various surface discolorations, and chilling injury are the major causes of the losses in marketability. In addition, some of the melons are excessively ripe on arrival, whereas others never reach a satisfactory degree of ripeness. These problems are attributable, at least partly, to variation in the degree of ripeness of the melons when shipped and to frequent omission of ethylene treatment prior to shipment of the melons.

The problems described might be alleviated, and thus the export market expanded, if recommendations for handling and transit conditions specifically tailored to long-distance shipments of honeydew melons were available. Alleviation of these problems also may aid in extending the domestic marketing season for these melons. Current practices are patterned mainly after recommendations that were developed for domestic shipments, which are in transit a maximum of about 10 days (18). In contrast, shipments to the Far East require 2 to 3 weeks. For domestic shipments, treatment of the melons with ethylene is recommended to assure satisfactory ripening. This treatment is frequently omitted in shipments to the Far East or prior to domestic storage because of the fear that it might result in excessive ripening during 2 weeks or more of transit or storage at about 7.5°C (45°F), the currently used temperature.

Export shipments of honeydew melons might be increased and extension of the domestic marketing period might be possible, if procedures could be devised that would minimize all aspects of deterioration of the melons while enhancing the prospect of satisfactory ripening. Earlier endeavors toward these goals (8, 9, 10, 11) have demonstrated that honeydew melons that have been treated 18 hr with 1000 parts per million (p/m) ethylene at about 20°C (68°F) can be stored almost 3 weeks at 2.5° or 5°C (36° or 41°F), temperatures in the chilling range, without developing serious chilling injury (CI). The melons also did not lose their capacity to ripen once they were placed at room temperature (20°C).

This publication deals with results obtained when honeydew melons were treated with ethylene at temperatures typical of those encountered during the harvest season in the West and Southwest. These temperatures typically range from about 20° to 40°C (68° to 104°F), depending upon season and time of day of harvest. Previously published information derived from this series of experiments will be used where necessary for clarity and so that those in the trade can adequately evaluate the procedures and results to be presented. The results will emphasize the influence of the various treatments on ripening, development of decay, chilling injury and other disorders, and on the overall potential eating quality of the melons.

¹Lipton is a plant physiologist, Horticultural Crops Research Laboratory, P.O. Box 8143, Fresno, Calif. 93747; Mackey is a biometrician, Western Regional Research Center, 800 Buchanan Street, Berkeley, Calif. 94710.

Materials and Methods

General

The test melons were harvested and packed in fiber-board boxes by various California shippers from 1978 through 1981. The growing areas included the southeastern desert area (1978 and 1979 only) and the San Joaquin and Sacramento Valleys. The harvest season ranged from June through October. During the hot months, the melons were transported to Fresno in a compartment held at about 10°C (50°F). When the start of a test was delayed until the day after harvest, the melons were held overnight at 10° or 15°C (59°F). This delay can not be considered a curing treatment to reduce CI (10).

At the start of each test, the melons were weighed (± 1 g), rated for ripeness, and numbered for identification. The rating was based on a scale in which 1 = minimum horticultural maturity, 1.5 = fully mature, 2 = ripening initiated, 3 = ripe (ideal for eating), 4 = over-ripe, and 5 = senescent (16). We only used melons that initially were rated 1 or 1.5 for degree of ripeness (Class 1: well filled out and of normal size; ground color white but greenish aspect, due to translucent greenish speckles; blossom end hard to firm; no aroma; no waxy skin coating; may feel prickly or hairy. Class 1.5: color definitely white, no more than a trace of translucent green color; blossom end hard to slightly springy; no aroma; very little wax). Minor defects on the melons were marked to preclude confusion of symptoms at the examinations, but melons with defects that might affect storage life, such as cuts and bruises, were discarded.

The melons were examined twice during each test, after 16 to 20 days at 2.5°, 5°, or 7.5°C (36°, 41°, or 45°F) and after a final 2 or 3 days of ripening at 20°C (68°F). The lowest temperature is considered to be in

the chilling range for honeydew melons, and 5°C is regarded as the lowest safe temperature for their extended storage (8); 7.5°C is a commonly used transit temperature for these melons, and 20°C is good for their ripening. At each of these examinations, we weighed the melons, judged their degree of ripeness, strength of aroma on the blossom end (1 = none detectable, 3 = pleasant, and 5 = excessively strong), and overall appearance (9 = excellent, 7 = good, 5 = fair, lower limit of salability, 3 = poor, and 1 = extremely poor) (7). The degrees of severity of CI, decay, and of various surface discolorations were judged on a scale of 1 (none) to 9 (extreme) (7). Intermediate ratings were used as appropriate.

In 1980 and 1981, we also rated the degree of disintegration of the placental tissue associated with ripening, which, when severe, can result in liquefaction of this tissue. This condition, known as wet cavity, was rated on a scale where 1 = none, 2 = slight (definitely not objectionable), 3 = moderate (likely not objectionable), 5 = severe (definitely objectionable). Additionally, at the beginning of each test, we measured the soluble solids content (SSC) in 10 representative melons by methods that conform to California regulations (2) to gain some information about the internal quality of the melons.

Melons Exposed to Ethylene at 20°C (68°F)

In each test, 12 boxes of six melons (occasionally five) were randomized into three groups of four boxes. Two boxes of melons in each group were placed into stainless steel chambers and exposed at 20°C (68°F) to a continuous flow (1015 ± 10 ml/min) of 1000 p/m ethylene in 20 percent O₂/80 percent N₂ for 12, 18, or 24 hr. The other two boxes of each group were the controls, which were held in a separate room at 20°C for the same respective periods. At the end of each specified interval, one box of controls and one of treated melons from each group of four were transferred to a room held at 2.5°C (36°F) and the remaining two boxes to a room held at 5°C (41°F). In addition to the six boxes of controls that were held at 20°C for the three periods, four others were placed at the start of each test in a room held at 7.5°C (45°F) to simulate current commercial practice. All temperatures were controlled within $\pm 0.5^\circ\text{C}$ ($\pm 1^\circ\text{F}$). Once the melons had cooled to the required temperature, each box was enclosed in a perforated (at least 48 holes 6 mm [$\frac{1}{4}$ inch] in diameter) polyethylene bag to minimize moisture loss during storage.

Melons Exposed to Ethylene at 30° or 40°C (86° or 104°F)

In each of these tests, eight boxes of melons were randomized into two groups of four boxes. Two boxes of melons in each group were treated with ethylene as described above, but at 30° or 40°C (86° or 104°F) and only for 12 or 18 hr. A 24-hr treatment was omitted since the results of the earlier tests at 20°C (68°F) led us to believe that this period of exposure at higher temperatures would result in excessively rapid ripening. The controls were held in stainless steel chambers in the same rooms as those treated, but the chambers were flushed continuously (also at 1015 ± 10 ml/min) with compressed air released from high-pressure cylinders. At the end of the 12 or 18 hr, the melons were stored as described for those treated at 20°C. In addition to the controls that were held at 30° or 40°C during the treatment period, four boxes of controls were placed at 7.5°C (45°F) at the start of each test and, in 1981 only, four others were heated to 30° or 40°C and then placed at 7.5°C. These latter controls, designated 7.5H, were included to simulate the conditions that likely exist when initially very warm melons are cooled to and shipped at 7.5°C.

Since the melons were not necessarily at the desired temperature for the treatments when we obtained them, we placed those designated to be at 30° or 40°C (86° or 104°F) in a forced draft oven for various periods after they had been weighed and rated for degree of ripeness. The oven was set only 5°C (9°F) above the desired temperature to avoid any excessive heating. Warming was concluded when the melons were within 5°C or less of the desired temperature at a depth of 10 mm, as measured with a spear-type thermister probe. The warming required between 1 and 3 hr, depending on the initial temperature of the fruit. Upon removal from the oven, the appropriate boxes of melons were moved immediately to the room in which the ethylene treatment was then carried out, whereas the 7.5H lots were placed in the room held at 7.5°C (45°F).

During the last two tests in 1980 (one each at 30° and 40°C [86° and 104°F]) and during all tests in 1981, we also measured the rate of CO₂ production of each box of melons and ethylene production of the controls. Measurements were made once or twice during the 12 or 18 hr at 30° or 40°C. The gas flow rate was 1015 ± 10 ml/min, which held the CO₂ concentration always below 1 percent and mostly below 0.5 percent. The methods of analysis were previously described (12).

Statistical Analysis of Data

Rate of Ripening. Yearly averages were used in five-factor analyses of variance with years considered as the random effect. The five-way interaction and four three-way interactions with years were tested for homogeneity with Bartlett's test (15) and subsequently pooled for error.

Percentage Data. Factorial analyses of variance were run on response proportions (also yearly) to identify the most probable interactions ($p > 0.20$). Confidence intervals (95 percent) based on binomial theory (20) were then constructed for these subclasses. Comparisons among treatments and with the controls were judged significant if the respective confidence intervals did not overlap. If confidence intervals overlapped each other but not the opposing estimates, 95 percent confidence intervals were constructed on differences. In this case, significance was inferred when an interval did not include zero.

In most cases, a normal approximation of the binomial was used to construct confidence intervals. For small sample sizes and proportions near zero or one, however, exact confidence intervals were computed for individual estimates, and Fisher's Exact Test was used for comparisons (15). Probabilities from Fisher's test were multiplied by two to make the tests two-tailed.

Data for tests at 20°, 30°, or 40°C (68°, 86°, or 104°F) were analyzed separately because the tests were run at different times.

Results

Rates of Carbon Dioxide and Ethylene Production

The rate of CO₂ production of honeydew melons was substantially higher at each successive 10°C (18°F) temperature increment when measured between 15 and 24 hr after the melons were placed at 20°, 30°, or 40°C (68°, 86°, or 104°F). As would be expected, the rates were higher (by 50 to 70 percent) in lots being treated with ethylene than in the control lots (table 1).

The rate of ethylene production (controls only) also was higher at 40°C (104°F) than at 30°C (86°F), and it was higher at both temperatures than that reported for 20°C (68°F) (16) after similar intervals (table 1).

Table 1.—Rates of CO₂ and ethylene production of honeydew melons as influenced by high temperatures and ethylene treatment^{1,2}

Temperature (°C)	CO ₂ production ³		Ethylene production (control)
	Control	Ethylene treated ⁴	
	Mg/kg-hr	Mg/kg-hr	μl/kg-hr
20	24	36	⁵ ~1
30	53	91	3
40	76	120	6

¹Mean rates based on 3 or 4 tests (2 boxes/test; 5 or 6 melons/box).

²Rates measured about 24 and 15.5 hr after melons were placed at 20°, 30°, or 40°C (68°, 86°, or 104°F), respectively.

³Standard errors of means, based on variance among tests were for CO₂ production at 20°C (68°F), 6; at 30° or 40°C (86° or 104°F), 7; for ethylene production at 30° or 40°C, 1.5.

⁴At 1000 p/m in 20 percent O₂/80 percent N₂.

⁵From (16).

Rate of Ripening

Exposure of honeydew melons to ethylene for 12, 18, or 24 hr (20°C treatment only) before they were stored at 2.5° or 5°C (36° or 41°F) speeded up the rate of ripening (expressed in units of change) at these low temperatures relative to the controls, whether the treatment was at 20°, 30°, or 40°C (68°, 86°, or 104°F) (fig. 1). For the ethylene-treated fruit, the rates were two to four times as high as for the controls that were exposed to the high temperatures simultaneously with those treated with ethylene. Additionally, the rates were two to three times as high as for the controls that immediately were stored at 7.5°C (45°F).

A 6-hr increase in the duration of the ethylene treatment tended to increase the rate of ripening regardless of the temperature at which the treatment was applied, and the effect was evident whether subsequent storage was at 2.5° or 5°C (36° or 41°F). Following treatment at 20° or 40°C (68° or 104°F), the effect was greater during storage at 5° than at 2.5°C; we do not know why the reverse was the case following treatment at 30°C (86°F).

The controls that were held 12 to 24 hr at 20°, 30°, or 40°C (68°, 86°, or 104°F) and then were stored at 2.5° or 5°C (36° or 41°F) ripened at rates about equal to those of the melons stored at 7.5°C (45°F), whether the latter were initially heated to 30° or 40°C (1981 only). Apparently, holding honeydew melons 12 hr or more at 20°, 30°, or 40°C helps accelerate subsequent ripening, although much less than when they have been exposed to ethylene at these warm temperatures. This high-temperature effect likely is genuine and not a result of slower cooling of the warm melons to the storage temperature since all melons had cooled to the respective storage temperatures within 12 hr or less.

The rate of ripening during the 2 or 3 days at 20°C (68°F) subsequent to storage at low temperature was not affected consistently by previous conditions of treatment or storage. Melons that were treated at 20°C (fig. 1 *left*) for 12 or 18 hr and then stored at 2.5°C (36°F) ripened less during storage than during the final 2 days at 20°C. Among all other treated lots (fig. 1), more ripening occurred during cold storage than during subsequent holding at 20°C. Thus, the total amount of ripening that occurred was determined largely by the rate of ripening at the low temperatures. This pattern prevailed mainly among those controls held at 40°C (104°F) before cold storage.

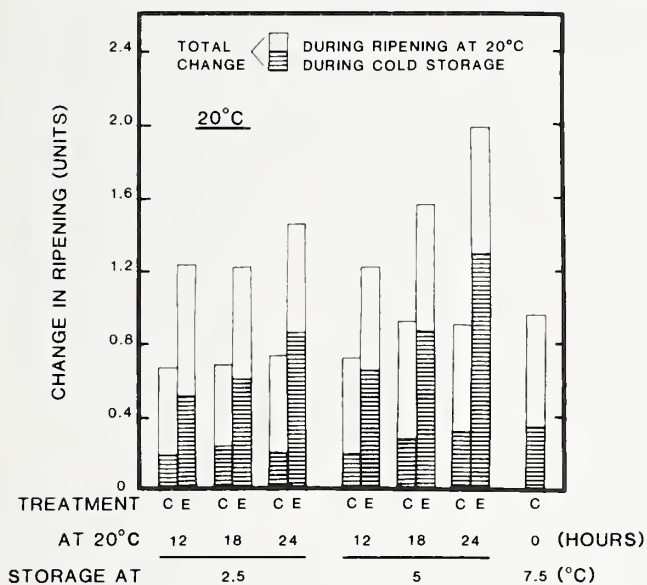
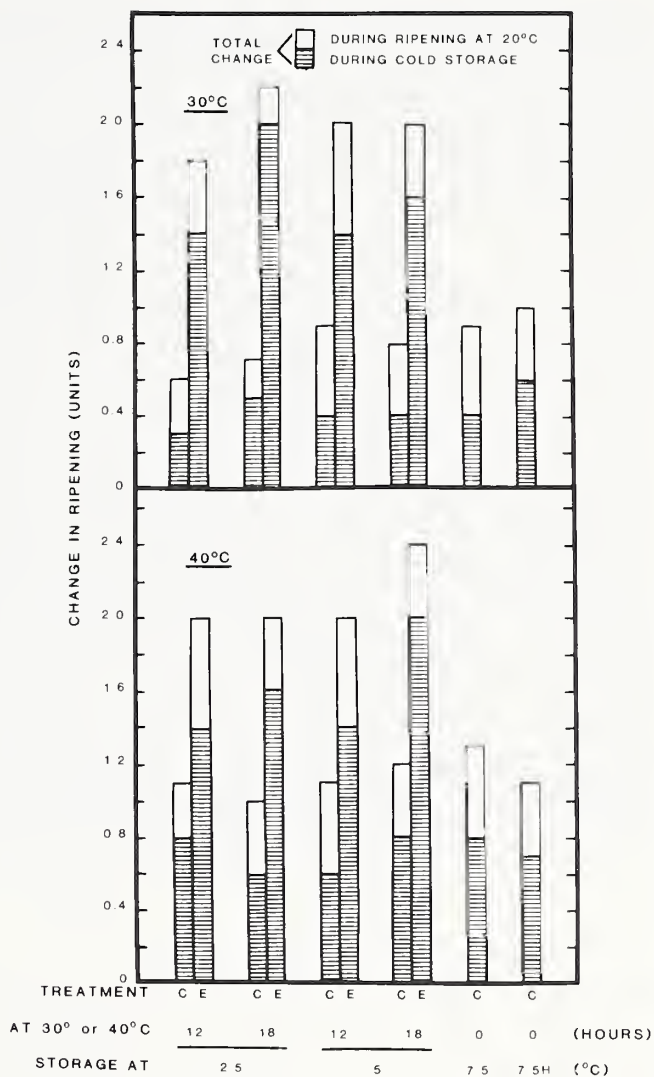


Figure 1.—*Left*, Change in degree of ripeness of honeydew melons during 16 to 20 days of cold storage at the temperatures indicated and during a subsequent 2 or 3 days at 20°C (68°F) if treated (E) or not treated (C) at 20°C (68°F) with ethylene for various periods before their storage. For example, a 1-unit change in ripeness involved a change from a mean ripeness degree of 1.5 to 2.5. For each interval, LSD, 5-percent level, 0.24. *Right*, Change in degree of ripeness of honeydew melons during 16 to 20 days of cold storage at the temperatures indicated and during a subsequent 2 or 3 days at 20°C (68°F) if treated (E) or not treated (C) at 30° or 40°C (86° or 104°F) with ethylene for various periods before their storage. For example, a 1-unit change in ripeness involved a change from a mean ripeness degree 1.5 to 2.5. For each interval, LSD, 5-percent level, for 30°C, 0.25; for 40°C, 0.18.



Overall, the rate of ripening of these melons mainly was a function of the ethylene treatment; however, its duration only moderately modified the effect of the ethylene in the direction one would expect. We do not know why storage at 2.5°C (36°F) sometimes resulted in a greater rate of ripening than storage at 5°C (41°F).

Degree of Ripening

For practical purposes, it is the degree of ripening that occurs during storage rather than the rate of ripening that is of interest. If ripening is slow, the melon may not have reached an edible state by the time the consumer takes it home; if the rate is rapid, the melon may be overripe. Thus, the best expression of a desirable

rate of ripening is the proportion of melons that is eating ripe or almost so (maturity classes 3 and 2, respectively) when consumers buy the melons. In lots of melons treated at 20°C (68°F), about 80 percent were in maturity class 2 or riper, but among the controls only about 50 percent had ripened to this stage (table 2 A). The proportion of melons in class 2 or 3 (class 2 or riper minus class 4 or 5) was about 20 to 40 percent higher in the treated lots stored at 2.5°C (36°F) than in those stored at 5°C (41°F), because at 5°C more melons had ripened to class 4 or 5 (table 2 A). Thus, for melons treated at 20°C with ethylene, storage at 2.5°C would be preferable to storage at 5°C. Among the controls, fewer than 60 percent of the melons had reached the

Table 2.—Ripening of honeydew melons as influenced by duration of ethylene treatment at 20°, 30°, or 40°C and by subsequent storage at several temperatures¹

Temperature and type of prestorage treatment		Duration of prestorage treatment	Percent melons that had reached a given ripeness class after storage at temperatures cited plus ripening at 20°C ²								
			Class 2 or riper			Class 4 or 5			Class 2 or 3 ³		
			Storage temperature (°C)								
			2.5	5.0	7.5	2.5	5.0	7.5	2.5	5.0	7.5
		<i>Hours</i>	<i>Percent melons in each category⁴</i>								
A. 20°C											
Ethylene		12	79	69	—	9	12	—	70	57	—
		18	78	79	—	10	<u>24</u>	—	68	55	—
		24	81	89	—	9	<u>37</u>	—	72	52	—
	Mean		<u>79</u>								
Control		0	—	—	<u>58</u>	—	—	<u>7</u>	—	—	51
		12	60	43	—	2	2	—	58	41	—
		18	55	53	—	0	11	—	55	42	—
		24	55	54	—	2	<u>2</u>	—	53	52	—
	Mean		<u>53</u>								

B. 30°C											
Ethylene		12	<u>96</u>	<u>96</u>	—	<u>20</u>	<u>19</u>	—	76	77	—
		18	<u>100</u>	<u>96</u>	—	<u>31</u>	<u>21</u>	—	69	75	—
Control ⁵ 7.5		0	—	—	<u>52</u>	—	—	<u>4</u>	—	—	48
	7.5H	0	—	—	60	—	—	3	—	—	59
12		<u>13</u>	<u>52</u>	—	4	<u>0</u>	—	9	52	—	
18		<u>48</u>	<u>46</u>	—	<u>0</u>	<u>0</u>	—	48	46	—	

C. 40°C											
Ethylene		12	<u>100</u>	<u>96</u>	—	<u>17</u>	<u>30</u>	—	83	66	—
		18	<u>100</u>	<u>96</u>	—	<u>17</u>	<u>32</u>	—	83	64	—
Control ⁵ 7.5		0	—	—	<u>64</u>	—	—	<u>8</u>	—	—	56
	7.5H	0	—	—	65	—	—	6	—	—	60
12		<u>50</u>	<u>57</u>	—	<u>3</u>	<u>7</u>	—	47	50	—	
18		<u>54</u>	<u>73</u>	—	<u>0</u>	<u>8</u>	—	54	65	—	

¹The melons, initially in ripeness class 1, were stored 16 to 20 days at 2.5°, 5°, or 7.5°C (36°, 41°, or 45°F) and then 2 or 3 days at 20°C (68°F). Ethylene-treated melons were exposed at 20°, 30°, or 40°C (86° or 104°F) to 1000 p/m of the gas for the periods given. The experiments at 20°, 30°, and 40°C are not directly comparable because they were run at different times.

²Ripeness classes: 1 = minimum horticultural maturity; 2 = ripening initiated; 3 = ripe; 4 = overripe; 5 = senescent (16).

³The percentage of melons in class 2 or 3 is the differences between those in class 2 or riper and those in class 4 or 5. The data for class 2 or 3 were not treated statistically.

⁴Underlined values of ethylene-treated lots differ at the 5 percent level from corresponding controls (solid line) and/or from controls held at 7.5°C (dashed line). The 7.5H treatment was not included in the analysis since it occurred in only 1 year.

⁵The 7.5 controls were placed immediately at that temperature; the 7.5H controls were warmed to 30° or 40°C, respectively, before being stored at 7.5°C; for details see "Methods and Materials."



Figure 2.—Color difference between melons treated (E) or not treated (CK) before storage with 1000 p/m ethylene for 18 hr and at 30°C (86°F) when photographed after they were stored 16 days at 5°C (41°F) plus 3 days at 20°C (68°F).

desirable range of ripeness. Further, keeping the control melons 12, 18, or 24 hr at 20°C before their storage at 2.5° or 5°C had little effect on ripening relative to those that were placed immediately at 7.5°C (45°F) (table 2 A); thus, a delay of cooling was equivalent to storage at the higher temperature.

For melons initially treated at 30°C (86°F), 12- and 18-hr exposures to ethylene were about equally effective, whether subsequent storage was at 2.5° or 5°C (36° or 41°F) and regardless of which ripeness category is considered (table 2 B; fig. 2). Again, fewer than 60 percent of the control melons were desirably ripe. Melons warmed to 30°C before being stored at 7.5°C (45°F) (control 7.5H) ripened about equally as those not warmed before storage (control 7.5).

The results for melons treated at 40°C (104°F) were similar to those treated at 30°C (86°F), except that subsequent storage at 2.5°C (36°F) was decidedly superior to storage at 5°C (41°F), where nearly one-third of the melons were overripe (table 2 C, fig. 4).

Melons that are fully mature (ripeness class 1.5) at harvest and need to be stored for 2½ to 3 weeks should not be treated with ethylene before storage. This is the case even when they are held between 2.5° and 5°C (36° and 41°F) because too many will be overripe at the end of storage. Among those treated at 20°C (68°F), 28 percent were overripe compared with 7 percent for the controls (difference significant at 5 percent level). Dura-

tion of ethylene treatment and subsequent storage temperature did not significantly influence these results. When the exposure to ethylene was at 30°C (86°F), 44 percent of those treated and 9 percent of the controls (difference significant at 5 percent level) were overripe. The results for those treated at 40°C (104°F) again were similar, except that the overripeness was less common for melons stored at 2.5°C (17 percent in those treated, 2 percent in the controls) than in those stored at 5°C (31 percent in those treated, 7 percent in the controls). The differences in both cases were significant at the 5 percent level. The incidence of overripeness was similar in the controls that were heated to 30° or 40°C before storage and in those that were not heated, and the means for both were similar to the means for the controls stored at 2.5° or 5°C.

We conclude that melons of maturity class 1.5, which are very resistant to chilling injury, should be cooled quickly to and stored at 2.5° to 5°C (36° to 41°F) if they are to be held 2½ to 3 weeks, or else too many would become overripe during this period, even without any deliberate exposure to ethylene.

Development of Aroma

The proportion of melons with detectable or desirable aroma invariably was higher in lots that were treated with ethylene before cold storage than in the corresponding controls or in the controls that were stored at 7.5°C (45°F) (table 3).

Melons treated at 20°C (68°F) and stored at 5°C (41°F) more readily developed aroma (class 2 or greater) than those stored at 2.5°C (36°F), but the difference was statistically significant only for the 12-hr exposure. When stored at 2.5°C, more melons developed aroma when they previously were held at 20°C for 24 hr than for a shorter period, whether or not they were exposed to ethylene.

In melons treated with ethylene, an increase in exposure time frequently led to an increase in the proportion of melons with detectable or desirable aroma (class 2 or 3), although the differences were minimal in some cases. Among the controls, a 6-hr difference in exposure to the high temperature or heating them to 30° or 40°C (86° or 104°F) before storing them at 7.5°C (45°F) had little effect on the proportion of melons in the desirable range of aroma.

Treatment with ethylene tended to increase the percentage of melons with excessively strong aroma relative to the controls, regardless of the temperature of treatment and particularly during subsequent storage at 5°C (41°F) rather than 2.5°C (36°F) (table 3). Among the controls, however, melons without any discernible aroma (aroma rating = 1; $100 - [\text{percentage in class 2 or 3 plus percentage in classes 4 or 5}]$), an undesirable condition, accounted for about 40 to 75 percent of all melons.

Melons treated with ethylene clearly were more likely to develop a desirable aroma than those not treated. Also, storage at 2.5°C (36°F) was preferable to storage at 5°C (41°F) if treatment was at 30° or 40°C (86° or 104°F), but not if it was at 20°C (68°F).

Development of Wet Cavity

Development of wet cavity, the result of the disintegration of the placenta of the melons, tends to accompany ripening in honeydew melons. When the placenta liquefies, it may spill out when the melon is cut open; thus, the condition may be objectionable.

Overall, the incidence of wet cavity was slightly higher in melons exposed to ethylene than in the controls held at 20°, 30°, or 40°C (68°, 86°, or 104°F) (14 vs. 10 percent), but the difference was not statistically significant. In the controls that were held at 7.5°C (45°F), the incidence averaged 8 percent and did not differ significantly from the mean for any other treatment. Apparently, the development of wet cavity was only slightly influenced by our postharvest treatments.

Table 3.—Development of aroma in honeydew melons as influenced by duration of ethylene treatment at 20°, 30°, or 40°C and by subsequent storage at several temperatures¹

Temperature and type of prestorage treatment	Duration of prestorage treatment	Percent melons that had reached a given aroma after storage at temperatures cited plus ripening at 20°C ²									
		Class 2 or greater			Class 4 or 5			Class 2 or 3 ³			
		Storage temperature (°C)									
		2.5	5.0	7.5	2.5	5.0	7.5	2.5	5.0	7.5	
		<i>Hours</i>	<i>Percent melons in each category⁴</i>								
A. 20°C											
Ethylene	12	*52	*68	—	6	11	—	46	57	—	
	18	\$59	74	—	5	13	—	54	61	—	
	24	\$77	96	—	11	<u>22</u>	—	66	74	—	
Control	Mean	<u>73</u>									
	0	—	—	<u>53</u>	—	—	<u>6</u>	—	—	47	
	12	*26	*42	—	2	2	—	24	40	—	
	18	\$34	50	—	1	8	—	33	42	—	
	24	\$42	51	—	1	10	—	41	41	—	
	Mean	<u>41</u>									
B. 30°C											
Ethylene	12	91	94	—	6	<u>20</u>	—	85	74	—	
	18	100	97	—	<u>14</u>	<u>31</u>	—	86	66	—	
Mean		<u>96</u>	<u>97</u>		10	<u>26</u>					
	Control ⁵ 7.5	0	—	—	<u>51</u>	—	—	<u>4</u>	—	—	46
7.5H		0	—	—	59	—	—	8	—	—	51
		12	29	51		3	9	—	26	42	—
		18	31	46		<u>0</u>	<u>3</u>	—	31	43	—
Mean		<u>30</u>	<u>49</u>		1	<u>6</u>					
C. 40°C											
Ethylene	12	92	94	—	8	33	—	84	61	—	
	18	100	100	—	8	26	—	92	74	—	
Mean		<u>96</u>	<u>97</u>		8	<u>30</u>					
	Control ⁵ 7.5	0	—	—	<u>45</u>	—	—	<u>14</u>	—	—	31
7.5H		0	—	—	60	—	—	18	—	—	42
		12	25	44		8	3	—	17	41	—
		18	28	58		3	14	—	25	44	—
Mean		<u>26</u>	<u>51</u>		6	<u>8</u>					

¹The melons, initially in ripeness class 1, were stored 16 to 20 days at 2.5°, 5°, or 7.5°C (36°, 41°, or 45°F) and then 2 or 3 days at 20°C (68°F). Ethylene-treated melons were exposed at 20°, 30°, or 40°C (86° or 104°F) to 1000 p/m of the gas for the periods given. The experiments at 20°, 30°, and 40°C are not directly comparable because they were run at different times.

²Aroma classes: 1 = none detectable; 3 = pleasant; 5 = excessively strong.

³The percentage of melons in class 2 or 3 is the difference between those in class 2 or greater and those in class 4 or 5. The data for class 2 or 3 were not treated statistically.

⁴Underlined values of ethylene-treated lots differ at the 5 percent level from corresponding controls (solid line) and/or from controls held at 7.5°C (dashed line). Pairs of values designated by * or \$ differ at the 5 percent level. The 7.5H treatment was not included in the analysis since it occurred in only 1 year.

⁵The 7.5 controls were placed immediately at that temperature; the 7.5H controls were warmed to 30° or 40°C, respectively, before being stored at 7.5°C; for details see "Methods and Materials."



Figure 3.—Reddish-tan discoloration associated with (top) moderate (rating 5) or (bottom) severe (rating 7) chilling injury.

Defects

Chilling Injury. Exposing honeydew melons to 1000 p/m ethylene before their storage at 2.5°C (36°F) almost invariably reduced the incidence of chilling injury (CI) as compared with the controls held at 2.5°C (table 4). The effect was similar whether treatment was at 20°, 30°, or 40°C (68°, 86°, or 104°F) and regardless of duration of treatment (12, 18, or 24 hr at 20°C and 12 or 18 hr at 30° or 40°C). In the treated melons, the incidence of trace or slight CI was always less than 10 percent; moderate or more severe CI (fig. 3) was virtually absent. In the controls held at 2.5°C, the incidence of trace to slight CI ranged from 0 to 17 percent and that of moderate or worse CI ranged from 0 to 14 percent.

Exposing the untreated melons to 30° or 40°C (86° or 104°F) for 18 hr rather than 12 hr not only did not reduce the incidence of CI, but such exposures induced a trend in the opposite direction (table 4). For those held at 20°C (68°F), however, the incidence of CI was lower in melons warmed 24 hr than in those warmed 12 or 18 hr. No visible CI developed in melons stored at 5° or 7.5°C (41° or 45°F).

Table 4.—Incidence of chilling injury (CI) in honeydew melons as influenced by ethylene treatment at 20°, 30°, or 40°C and by subsequent storage at 2.5°C¹

Treatment		Incidence of chilling injury					
		Trace or slight			Moderate or worse		
		Melon temperature (°C) during treatment					
Type	Duration	20	30	40	20	30	40
<i>Hours</i>		<i>Percent injured melons</i>					
Ethylene	12	3	9	6	2	0	0
	18	2	3	0	0	0	0
	24	0	—	—	0	—	—
Control	12	9	17	0	1	0	6
	18	8	12	3	3	14	3
	24	3	—	—	0	—	—

¹The melons, initially in ripeness class 1, were stored 16 to 20 days at 2.5°C (36°F). Ethylene-treated melons were exposed at the temperatures given to 1000 p/m of the gas. The experiments at 20°, 30°, and 40°C (68°, 86°, and 104°F) are not directly comparable because they were run at different times.



Figure 4.—*Top*, Color difference between melons not treated (left) and treated (right) with 1000 p/m ethylene for 12 hr and at 40°C (104°F) before storage when photographed after they were stored 18 days at 2.5°C (36°F) plus 2 days at 20°C (68°F). The gray discoloration on two of the nontreated melons is discussed in detail under "Gray Areas on Melons." *Bottom*, Color difference between

melons not treated (left) or treated (right) with 1000 p/m ethylene for 12 hr and at 40°C (104°F) before storage when photographed after they were stored 18 days at 5°C (41°F) plus 2 days at 20°C (68°F). The gray discoloration on two of the nontreated melons is discussed in detail under "Gray Areas on Melons."

Overall, an ethylene treatment for 12 to 18 hr at 20° to 40°C (68° to 104°F) can be relied upon to virtually eliminate the development of CI in honeydew melons during 16 to 20 days of subsequent storage at 2.5°C (36°F), a temperature otherwise in the chilling range. Exposure to high temperatures alone, however, without ethylene treatment, most likely will not be of any benefit in this respect.

Gray Areas on Melons. In 19 out of 24 tests, some melons (overall incidence for 24 tests, 4.8 percent) developed gray surface areas (fig. 4, *top*) of various sizes during cold storage, a defect already noted earlier (9). These areas were distinctly outlined; were not sticky, unlike those reported to occur in CI (21); were as firm as the surrounding normal tissue; and did not involve the underlying flesh. Unlike most defects, which increase in severity subsequent to cold storage, the gray discoloration faded or even disappeared completely in 82 percent of the affected melons during the 2 or 3 days at 20°C that followed cold storage. Graying was slightly more common on fruit treated with ethylene than on the controls (incidence 7 percent vs. 2 percent) and on fruit stored at 2.5°C (36°F) than at 5° or 7.5°C (41° or 45°F) (incidence 6, 3, and 2 percent, respectively). The temperature (20°, 30°, or 40°C [68°, 86°, or 104°F]) at which the melons were held before cold storage had no consistent effect on the incidence of the gray discoloration (5, 6, and 3 percent, respectively). However, those that were held 12 hr at the high temperature and then stored at 2.5°C tended to be affected more frequently than those treated 18 or 24 hr (incidence, 9, 4, and 4 percent, respectively).

The findings that (1) the graying was most common at 2.5°C (36°F) and in lots exposed to the warm temperatures for the shortest period before their storage at 2.5°C and that (2) the graying tended to disappear during the 2 to 3 days at 20°C (68°F) suggest that the graying might be a symptom of CI (8). In contradiction, (1) the graying was not evident in even a single melon that showed the typical reddish-tan discoloration associated with CI (fig. 3) and (2) the incidence of graying was higher in melons that were treated with ethylene. Both points argue against the graying being a symptom of CI, especially since ethylene treatment consistently reduced the incidence of the chilling-induced reddish-tan discoloration in these and earlier tests (10, 11). Additionally, there was no relationship between the occurrence of graying and solar yellowing (SY). If graying

were associated with CI, then graying should have been less common in tests with much SY since melons with SY are much less susceptible to CI than those without SY (11).

Although the graying is not a major defect of honeydew melons stored for a few weeks, it does detract substantially from the appearance of affected melons. Thus, knowing the major contributory factor to the defect would have been desirable. Unfortunately, our data permit no definitive conclusions in this respect.

Decay

After Cold Storage. Immediately after cold storage, decay was minimal regardless of treatment. Traces of decay that were noticeable were mostly confined to the area surrounding the severed stem and, secondarily, to small surface injuries.

After Cold Storage Plus Ripening at 20°C (68°F). The total incidence of decay, that is, any amount detectable by inspection of the melons (rating, 2 or higher) was not increased significantly by treatment of the melons with ethylene for 12 or 18 hr at 20°C (68°F). However, treatment for 24 hr led to a substantially higher incidence of decay in the treated lots than in the corresponding controls (table 5 A). The trend was the same for moderate or worse decay (severity rating 4 or higher).

When ethylene was applied to melons at 30°C (86°F), the treatment resulted in a twofold to fourfold increase in the incidence of melons with decay rated 2 or higher (any amount of decay) as compared with the corresponding controls or with the controls placed immediately at 7.5°C (45°F) (table 5 B). Duration of treatment had no significant effect on the incidence of decay rated 2 or higher when storage was at 2.5°C (36°F), but when storage was at 5°C (41°F), the 12-hr treatment showed less decay than the 18-hr one. In contrast, temperature of subsequent storage had no significant effect on the incidence of decay rated 2 or higher; however, warming the melons to 30°C before their storage at 7.5°C resulted in more decay than immediate transfer to 7.5°C.

Decay rated 4 or higher (definitely objectionable decay) also was more common in melons treated at 30°C (86°F) than in the corresponding lots that had not been exposed to ethylene before their storage at 2.5°C (36°F). The incidence of decay did not differ significantly among treated and control melons stored at 5°C (41°F), but the difference between treated lots stored at 5°C and the controls stored at 7.5°C (45°F) was significant (table 5 B).

Table 5.—Incidence of decay in honeydew melons as influenced by ethylene treatment at 20°, 30°, or 40°C and by subsequent storage at several temperatures¹

Temperature and type of prestorage treatment	Duration of prestorage treatment	Percent melons with a given severity of decay after storage at temperatures cited plus ripening at 20°C ²					
		Rated 2 or higher			Rated 4 or higher		
		Storage temperature (°C)					
		2.5	5.0	7.5	2.5	5.0	7.5
	<i>Hours</i>	<i>Percent melons in each category³</i>					
A. 20°C							
Ethylene	12	52	55	—	27	19	—
	18	55	47	—	14	18	—
	24	<u>58</u>	<u>64</u>	—	<u>22</u>	16	—
Control	0	—	—	<u>49</u>	—	—	<u>17</u>
	12	44	52	—	22	25	—
	18	43	45	—	10	16	—
	24	<u>39</u>	<u>40</u>	—	<u>7</u>	16	—

B. 30°C							
Ethylene	12	<u>66</u>	* <u>54</u>	—	<u>11</u>	<u>14</u>	—
	18	<u>80</u>	* <u>77</u>	—	<u>20</u>	<u>26</u>	—
Control ⁴ 7.5	0	—	—	<u>36</u>	—	—	<u>3</u>
	0	—	—	54	—	—	8
7.5H	12	<u>26</u>	<u>23</u>	—	<u>0</u>	9	—
	18	<u>20</u>	<u>36</u>	—	<u>0</u>	8	—

C. 40°C							
Ethylene	12	<u>61</u>	<u>61</u>	—	8	14	—
	18	<u>69</u>	<u>47</u>	—	19	14	—
Control ⁴ 7.5	0	—	—	<u>44</u>	<u>14</u>	—	<u>6</u>
	0	—	—	53	—	—	17
7.5H	12	<u>36</u>	<u>31</u>	—	6	3	—
	18	<u>25</u>	<u>25</u>	—	6	8	—
						<u>6</u>	

¹The melons were stored 16 to 20 days at 2.5°, 5°, or 7.5°C (36°, 41°, or 45°F) and then 2 or 3 days at 20°C (68°F). Ethylene-treated melons were exposed at 20°, 30°, or 40°C (86° or 104°F) to 1000 p/m of the gas for the periods given. The experiments at 20°, 30°, and 40°C are not directly comparable because they were run at different times.

²Decay rating: 2 = trace, does not impair market quality of melon; 4 = slight to moderate, definitely reduces marketability of melon.

³Underlined values of ethylene-treated lots differ at the 5 percent level from the corresponding (solid line) and/or from the controls held at 7.5°C (dashed line). Asterisks signify that the pairs of values so designated differ at the 5 percent level. The 7.5H treatment was not included in the analysis since it occurred in only 1 year.

⁴The 7.5 controls were placed immediately at that temperature; the 7.5H controls were warmed to 30° or 40°C, respectively, before being stored at 7.5°; for details see "Methods and Materials."

Among melons treated at 40°C (104°F), the lots exposed to ethylene had a higher incidence of decay than the controls. As with tests conducted at 30°C (86°F), warming the melons to 40°C before their storage at 7.5°C (45°F) aggravated decay rated 4 or higher.

An increase in the incidence of decay frequently is associated with CI, even when there are no specific symptoms of CI visible on the affected specimens. Thus, the question arises whether storage at 2.5°C (36°F), which is definitely in the chilling range for honeydew melons, induced more decay than storage at 5°C (41°F), where CI is rare. According to our data (table 5), differences in the incidence of decay were not related to increased susceptibility of the melon to CI at 2.5°C. When decay of any severity is considered, among the 14 comparisons possible between storage at 2.5° or 5°C, the incidence was about equal (within 3 percentage points) in seven cases, was higher at 2.5°C in four cases, and at 5°C in three cases. When decay of severity 4 or greater is considered, the results were even clearer: incidence was equal in four cases, higher at 2.5°C in three cases, and higher at 5°C in seven cases. Thus, incidence of decay appears to be more closely related to the degree of ripening that occurred during storage, rather than to any influence of CI. This situation prevailed, whether we consider the lots that were treated with ethylene or the controls.

Influence of Source of Melons. During each of the years during which these tests were conducted, the incidence of decay varied from test to test, regardless of any other variable. Thus, the decay potential of the melons obviously depended on some factor(s) independent of postharvest handling, especially since the physical injuries that might lead to decay occurred to an about equal extent in all lots of melons. Additionally, we excluded from our tests any melons with more than minor visible injuries. We conclude, therefore, that growing conditions influence the decay potential of honeydew melons even when neither inclement weather nor field chilling is involved. None of our data are a guide to what these conditions might be.

Location of Decay. The stem end was an important site for the initiation and further development of decay; it originated at and was confined to the stem end in about one-third of the fruits that showed any decay during the 4 years of our tests. Thus, a very small site accounted for a disproportionately high frequency of decay. We cannot evaluate the contributions of cuts or bruises to decay incidence because we excluded most melons with such defects from our tests; however, we did observe that small wounds tended to dry up and heal and rarely were sites of decay.

In about two-thirds of the cases where decay was evident, there was no particular pattern to its distribution; however, whereas the infections at the stem end tended to be some type of soft rot, lesions on the other parts of the melons were mostly dry and closely resembled those of *Alternaria* rot (17). Some of these lesions were only small tan to brown surface spots when the melons were removed from the three low temperatures and thus were not classified as being due to infections; however, after the melons had ripened 2 or 3 days at 20°C (68°F), some of the spots had become larger and darker and unquestionably were fungal lesions.

Since development of decay is one of the chief factors that limits the marketable life of honeydew melons, research on methods to minimize this cause of losses seems warranted. Three lines of investigation seem particularly appropriate. In respect to stem end decay, the influence of the length of stem left on the fruit on decay development should be determined. A stem length of about 2.5 cm (1 inch) is recommended for watermelons (19). Second, the efficacy of a rinse with sodium hypochlorite solution, which is a standard treatment for much produce, might also be investigated. Third, since exposing the melons to 40°C (104°F) for as long as 18 hr resulted in no more decay or in any other discernible injury than exposing them to 30°C (86°F) (table 5 B and C), the efficacy of heat treatments of honeydew melons for decay control might be tested. Such treatments have been used on cantaloups and green peppers (19). The three approaches suggested, if successful, might be more desirable than the use of fungicides because they would leave no residues and thus avoid any regulatory problems, particularly in export shipments.

Corrugations

In some melons of all treatments, a portion of the surface became uneven due to an alteration of sunken and normal tissue (fig. 5), a defect we termed "corrugation" (CR). The corrugation mostly covered ¼ to ½ of the surface of the melons; in a few cases, the entire surface was involved. The flesh below the corrugations

appeared normal to the unaided eye and was as firm as adjacent normal tissue. CR was substantially less prevalent among the ethylene-treated melons than in the corresponding controls. For melons treated at 30°C (86°F), the respective values were 6 and 15 percent, and for those treated at 40°C (104°F), they were 6 and 21 percent. Each pair of values differed at the 5 percent level. CR was most common and about equal in the controls that were stored at 7.5°C (45°F) whether they first were warmed to 30° or 40°C (26 and 39 percent, respectively). Both values are significantly (5 percent level) higher than any of the others cited.

We did not investigate the etiology of CR, but suggest that its development may be related to localized water loss. The mean weight loss (initial-final weight) of melons with CR rated 4 or higher (5 = moderate) during 1980 and 1981 was 2.6 percent and that of paired melons without CR from the same box was 2.3 percent ($df = 56$; $t = 1.969$; tabular t for 0.05 probability = 2.004). Although this difference is relatively small, if much of the water loss in melons with CR had been concentrated in relatively small areas, then the corrugation, a type of shriveling, logically could have followed. (Weight loss due to respiratory loss of CO_2 would not have exceeded 0.6 percent in ethylene-treated or control melons.) This mode of action would explain the lower incidence of CR in melons treated with ethylene than in any of the controls. The treated melons ripened more rapidly than the controls, as noted earlier, and thus would have a thicker and possibly more even cover of wax during storage. Thus, after the ethylene treatments, moisture loss would not only be lower in treated than control melons but also would be distributed equally over the surface and, therefore, would not lead to localized excessive moisture loss and consequent corrugation. This argument is supported by our observation that 23 percent of melons that were in ripeness class 1 initially showed CR after storage and ripening, but only 16 percent of those that were in class 1.5 ($df = 11$; $t = 3.464$; tabular t for 0.01 probability = 3.106).

Weight Loss

Weight loss differed minimally among treatments and was 2.2 percent or less at the first examination and 2.9 percent or less after the 2 or 3 days of ripening at 20°C (68°F). Consequently, excessive weight loss need not be a concern under the conditions of temperature and treatments that we used and that encompass those that would be found most commonly in commercial practice.



Figure 5.—Corrugation of surface of honeydew melon.

Quality of Melons

Appearance. Melons rated 5 or higher. Melons judged to be at the lower limit of salability for most American retail markets were rated 5. Melons rated 5 or higher thus encompass the maximum percentage of melons that likely would be marketable at retail, based solely on appearance. Virtually all (93 percent or more) melons, regardless of treatment, were in this category after cold storage, and 83 percent or more still were in this category after 2 or 3 days of ripening at 20°C (68°F), without any statistically significant pattern being evident. The decrease, which ranged from 0 to 14 percent for individual treatments, was due almost entirely to an increase in decay during ripening.

Based on this criterion alone, that is, the proportion of melons rated salable or better, no treatment provided any substantial advantage over another one.

Melons rated 7 or higher. Melons rated 7 have minor external defects that would not materially detract from their salability, as based on appearance, in most markets; those rated 9 have essentially no external defects. After cold storage, there was relatively little difference in the percentage of melons that were rated 7 or higher ("good to excellent") in appearance: At least 83 percent were in this category in all lots.

The results were substantially different at the second examination. Appearance worsened in all treatments during ripening at 20°C (68°F), mainly because of the development of various brown discolorations associated with overripeness or decay development. However, none of the lots treated at 20°C, differed significantly from each other, with 74 percent being the maximum proportion of melons in the "good to excellent" category. When melons were treated 12 hr at 30°C (86°F), 67 percent were rated 7 or higher, but 86 percent of the controls were in this category (difference significant at 5 percent level). Subsequent storage temperature (2.5° or 5°C; 36° or 41°F) did not affect the results significantly. The controls held at 7.5°C (45°F) without having been warmed to 30°C also were superior (83 percent rated 7 or higher) to the ethylene-treated lots. For melons that had been held 12 hr at 40°C (104°F) without ethylene, 72 percent still were judged to have a "good or excellent" appearance at the second examination. This percentage was significantly (5 percent level) higher than that (55 percent) for the controls held at 7.5°C; however, none of the ethylene-treated lots differed significantly from the corresponding controls (63 vs. 71 percent rated 7 or higher).

If we use appearance ratings of 7 or higher as the sole criterion by which to judge the merits of the various treatments, then none differed from each other when treatment was at 20°C (68°F). However, a 12-hr delay without exposure to ethylene was optimal for melons initially at 30° or 40°C (86° or 104°F).

Potential Eating Quality. So far, we have considered only external appearance as a criterion of quality. This criterion is important in judging the desirability of a honeydew melon; however, since the melons are bought to eat, factors that are related to eating quality are highly important in considering the merits of various postharvest procedures. These factors include aroma and other characteristics associated with degree of ripeness, such as firmness and color (16). We emphasized aroma in our evaluations, because some honeydew melons may have various characteristics of eating-ripe melons without emitting any detectable aroma.

We categorized the melons with an appearance rating of 5 or higher into two groups: acceptable and optimum potential eating quality. Melons were considered to meet the criteria for acceptable potential eating quality if they (1) were rated 5 or higher for external appearance, (2) were in ripeness class 2 or 3 (see "Methods and Materials"), and (3) had a detectable or pleasant aroma (rated 2 and 3, respectively). The melons had to be rated 7 or higher for external appearance and also had to meet the other two qualifications to meet the criteria for optimum potential eating quality.

Acceptable potential eating quality. For melons treated at 20°C (68°F), exposure to ethylene yielded about three times as much fruit of acceptable potential eating quality as the controls when the melons were examined after storage at 2.5° or 5°C (36° or 41°F) (table 6 A). Although the proportion of ethylene-treated melons in this quality category was relatively low after cold storage, it exceeded that for the controls held at 7.5°C (45°F) by a factor of two. Additionally, a 24-hr treatment was more effective than those of 12 or 18 hr, which did not differ significantly from each other. The advantage of the ethylene treatment was about halved during subsequent ripening at 20°C, but the difference between treated and control lots was still statistically significant.

When melons at 30°C (86°F) were exposed to ethylene, the results were almost the same as for those treated at 20°C (68°F) (table 6 B).

Melons that were at 40°C (104°F) when treated benefited from 12 or 18 hr of exposure to ethylene before their storage at 2.5°C (36°F) and from a 12-hr exposure when storage was at 5°C (41°F) (table 6 C). The 12-hr ethylene treatments followed by storage at 2.5° or 5°C also were superior to storage of the melons at 7.5°C (45°F). After ripening, the results were similar, although the percentage of acceptable melons tended to be lower than after cold storage.

Table 6.—Percent melons of acceptable potential eating quality as influenced by duration of ethylene treatment at 20°, 30°, or 40°C and by subsequent storage at several temperatures¹

Temperature and type of prestorage treatment		Duration of prestorage treatment	Percent melons of acceptable potential eating quality after storage at temperatures cited and after ripening at 20°C					
			After storage			After ripening		
			Storage temperature (°C)					
			2.5	5.0	7.5	2.5	5.0	7.5
		<i>Hours</i>	<i>Percent melons in each category²</i>					
A. 20°C								
Ethylene		12	44	45	—	36	53	—
		18	46	47	—	46	45	—
		24	62	57	—	55	55	—
	Mean		<u>53</u>			<u>47</u>		
Control		0	—	—	<u>25</u>	—	—	<u>33</u>
		12	5	13	—	17	28	—
		18	14	22	—	24	26	—
		24	14	24	—	33	31	—
	Mean		<u>16</u>			<u>28</u>		

B. 30°C								
Ethylene		12	66	83	—	66	63	—
		18	71	86	—	54	58	—
	Mean		<u>77</u>			<u>60</u>		
Control ³ 7.5		0	—	—	<u>26</u>	—	—	<u>41</u>
	7.5H	0	—	—	51	—	—	40
		12	20	29	—	23	43	—
		18	37	36	—	31	36	—
	Mean		<u>30</u>			<u>33</u>		

C. 40°C								
Ethylene		12	<u>78</u>	<u>81</u>	—	<u>53</u>	<u>53</u>	—
		18	<u>64</u>	56	—	<u>69</u>	44	—
Control ³ 7.5		0	—	—	<u>45</u>	—	—	<u>28</u>
	7.5H	0	—	—	50	—	—	30
		12	<u>39</u>	<u>19</u>	—	<u>17</u>	<u>25</u>	—
		18	<u>28</u>	44	—	<u>19</u>	39	—

¹The melons were stored 16 to 20 days at 2.5°, 5°, or 7.5°C (36°, 41°, or 45°F) and then 2 or 3 days at 20°C (68°F). Ethylene-treated melons were exposed at 20°, 30°, or 40°C (68°, 86°, or 104°F) to 1000 p/m of the gas for the periods given. The experiments at 20°, 30°, and 40°C are not directly comparable because they were run at different times.

²Underlined values of ethylene-treated lots differ at the 5 percent level from the corresponding control (solid line) and/or from the controls held at 7.5°C (dashed line). The 7.5H treatment was not included in the analysis since it occurred in only 1 year.

³The 7.5 controls were placed immediately at that temperature; the 7.5H controls were warmed to 30° or 40°C, respectively, before being stored at 7.5°C; for details see "Methods and Materials."

In treatments where the proportion of melons of acceptable potential eating quality was greater after ripening than after storage, the difference largely is attributable to the development of a perceptible or desirable aroma during ripening for the 2 or 3 days at 20°C (68°F) without a concurrent increase in the incidence or severity of defects, mainly decay.

If we take acceptable potential eating quality, a fairly lax standard, as our criterion of quality, then the ethylene treatments yielded more desirable melons after cold storage and after ripening at 20°C (68°F) than any of the controls. A 12-hr treatment would be adequate for melons treated at 30° or 40°C (86° or 104°F), but 24 hr would be preferable for treatment at 20°C (68°F). Overall, for melons treated with ethylene, storage at 2.5° or 5°C (36° or 41°F) was about equally satisfactory; thus, any temperature in this range would be suitable.

Optimum potential eating quality. Treatment of honeydew melons with ethylene before their storage at low temperatures also yielded the highest proportion of melons of optimum potential eating quality. This high standard of quality was met best with a 24-hr treatment for melons at 20°C (68°F) (table 7 A). After cold storage, the treated lots had about a twofold or greater advantage over any of the controls. As was the case for melons of acceptable potential eating quality, there was little or no difference between ethylene-treated lots that were stored at 2.5° or 5°C (36° or 41°F).

Honeydew melons gassed at 30°C (86°F) with ethylene behaved similarly to those treated at 20°C (68°F). After cold storage, about 2½ times as many treated as control lots were of optimal potential eating quality; after ripening, the difference was smaller but still statistically significant (table 7 B). Duration of treatment and storage temperature did not appreciably influence the results.

Ethylene treatment at 40°C (104°F) still was advantageous overall, but the main benefit after cold storage was from the 12-hr exposure (table 7 C). After ripening, the proportion of melons of optimal potential eating quality was relatively low in the treated and control lots, but the differences still were significant and attributable mainly to lots that had been stored at 2.5°C (36°F).

Judging by the data in table 7, treatment with ethylene clearly was advantageous relative to the controls, regardless of cold-storage temperature. The percentage of melons of optimum potential eating quality was relatively low, mainly because of decay development. Since the incidence of decay varied greatly with the source of melons, as noted earlier, shippers who historically have minimal problems with decay could take advantage of the benefits of ethylene treatment followed by storage or transit between 2.5° and 5°C (36° and 41°F), instead of at 7.5°C (45°F), with only a minimal risk of an increase in decay. The new procedure would not be advisable for those who frequently experience problems with decay when their honeydew melons are held for 2 weeks or more, whether in transit or stationary storage.

Comparison of Ratings for Appearance and Potential Eating Quality. The data on appearance and edible quality clearly demonstrate that external appearance alone is not necessarily a good criterion of the dessert quality of honeydew melons. The percentage of melons rated 5 or higher in appearance invariably exceeded the percentage of those with acceptable potential eating quality and the percentage of those rated 7 or higher exceeded that of melons of optimum potential eating quality. However, the ratios of the percentages of ethylene-treated melons rated 5 or higher or 7 or higher to those in the acceptable or optimal categories, respectively, were mostly much closer to 1 (range 1.2 to 2.4) than those of the controls stored at low temperature (range 2.0 to 19). This relationship would be expected, since ethylene not only helped induce aroma development but also desirable external symptoms of ripening, such as yellowing and wax development.

Soluble Solids Content

The soluble solids content (SSC) of the melons varied substantially among tests within a given year (1978, 7.2 to 10.6 percent; 1979, 10.0 to 13.9 percent; 1980, 8.4 to 10.5 percent; 1981, 8.4 to 10.7 percent) and among the years (means for tests conducted in 1978, 8.8 percent; 1979, 11.3 percent; 1980, 9.5 percent; 1981, 9.6 percent). In spite of the wide range in SSC, we found no relation between this criterion of quality and any of the other factors we evaluated.

Table 7.—Percent melons of optimum potential eating quality as influenced by duration of ethylene treatment at 20°, 30°, or 40°C and by subsequent storage at several temperatures¹

Temperature and type of prestorage treatment		Duration of prestorage treatment	Percent melons of optimum potential eating quality after storage at temperatures cited and after ripening at 20°C					
			After storage			After ripening		
			Storage temperature (°C)					
			2.5	5.0	7.5	2.5	5.0	7.5
		<i>Hours</i>	<i>Percent melons in each category²</i>					
A. 20°C								
Ethylene		12	44	42	—	26	34	—
		18	43	42	—	38	43	—
		24	58	54	—	43	45	—
	Mean		<u>50</u>	<u>49</u>		<u>35</u>	<u>40</u>	
Control		0	—	—	<u>22</u>	—	—	<u>23</u>
		12	5	13	—	8	17	—
		18	11	21	—	19	22	—
	Mean	24	<u>13</u>	<u>22</u>	—	<u>29</u>	<u>19</u>	—
			<u>10</u>	<u>19</u>		<u>19</u>	<u>19</u>	

B. 30°C								
Ethylene		12	57	80	—	57	49	—
		18	69	81	—	31	47	—
		Mean		<u>72</u>			<u>46</u>	
Control ³ 7.5		0	—	—	<u>23</u>	—	—	39
	7.5H	0	—	—	<u>46</u>	—	—	33
		12	20	29	—	20	43	—
		Mean	18	37	33	—	29	31
			<u>30</u>			<u>30</u>		

C. 40°C								
Ethylene		12	<u>78</u>	<u>81</u>	—	<u>36</u>	<u>47</u>	—
		18	50	47	—	<u>50</u>	33	—
		Mean		<u>64</u>			<u>42</u>	
Control ³ 7.5		0	—	—	39	—	—	<u>26</u>
	7.5H	0	—	—	47	—	—	21
		12	<u>33</u>	<u>17</u>	—	<u>8</u>	25	—
		Mean	18	28	44	—	<u>19</u>	44
			<u>31</u>			<u>24</u>		

¹The melons were stored 16 to 20 days at 2.5°, 5°, or 7.5°C (36°, 41°, or 45°F) and then 2 or 3 days at 20°C (68°F). Ethylene-treated melons were exposed at 20°, 30°, or 40°C (68°, 86°, or 104°F) to 1000 p/m of the gas for the periods given. The experiments at 20°, 30°, and 40°C are not directly comparable because they were run at different times.

²Underlined values of ethylene-treated lots differ at the 5 percent level from the corresponding control (solid line) and/or from the controls held at 7.5°C (dashed line). The 7.5H treatment was not included in the analysis since it occurred in only 1 year.

³The 7.5 controls were placed immediately at that temperature; the 7.5H controls were warmed to 30° or 40°C, respectively, before being stored at 7.5°C; for details see "Methods and Materials."

Discussion and Conclusions

Physiological Aspects

Chilling Injury. With the research reported here and previously (8, 9, 10, 11), we have sound evidence that CI in honeydew melons virtually can be prevented even during 2 weeks of storage at chilling temperatures if they are treated with ethylene before they are cooled to the desired transit temperature, that is, to between 2.5° and 5°C (36° and 41°F).

The amelioration in chilling injury at low temperatures and the desirable subsequent ripening at higher temperature we obtained with honeydew melons that were treated with ethylene before cold storage is analogous to the results obtained with Kelsey plums (3) and Elberta peaches (4) in South Africa over 40 years ago. The initial treatment of these tree fruits with acetylene (plums and peaches) or ethylene (plums) also seemed to induce sufficient ripening before cold storage to ameliorate CI during this period and permit ripening at a higher temperature thereafter. In contrast, mature-green tomatoes did not respond similarly (14). Since the fruit apparently must have reached a certain minimum stage of ripeness for the treatments to be effective (3, 4), we speculate that the tomatoes used by Ogura et al. (14) had not reached that minimum stage when they were treated with ethylene.

While we used 1000 p/m ethylene, a concentration used commercially to ripen various fruits, one-tenth of that concentration would be adequate (1) to induce ripening during the treatment if 100 p/m ethylene could be assured to quickly reach all melons in a transport vehicle or storage room and leakage were minimal during treatment. Since the ethylene used is relatively inexpensive, use of 1000 p/m would be desirable to make sure that melons in all parts of the van or storage are exposed to at least 100 p/m.

Volatile Production. The temperature at which maximum CO₂ or ethylene production occur is well known to vary among diverse fruits. In honeydew melons, the rates increased with temperature between 20° and 40°C (68° and 104°F). However, since the increase for both volatiles was greater between 20° and 30°C (86°F) than between 30° and 40°C (table 1), we can assume that 40°C is above the physiological optimum for these melons, even during the relatively brief periods we exposed them to this high temperature. Nevertheless, as judged by ethylene production, honeydews seem less sensitive to high temperatures than bananas (22), tomatoes (14), pears (13), or apple tissue (23); holding these fruits at 40°C, severely inhibited their evolution of ethylene.

Separation of Honeydew Melons by Maturity Class

In our tests, we frequently found melons of several degrees of ripeness in a given box of commercially packed fruit. A mixture of maturity classes 1 and 1.5 was common; a mixture of classes 1 through 2 was not unusual, and, occasionally, we even found class 3 melons mixed with less ripe ones. Such mixtures represent an obstacle to the delivery of honeydews of optimum eating quality to the distant consumer, since those of classes 2 or 3 would be overripe after 2 to 3 weeks in transit or storage.

In our tests, we used only fruit of classes 1 and 1.5. As we pointed out earlier, fruit of class 1 may benefit substantially from treatment with ethylene before being stored for 2 to 3 weeks at 2.5° to 5°C (36° to 41°F); however, fruit of class 1.5 would be too ripe if similarly exposed to ethylene. Thus, fairly accurate separations before shipment of honeydews of these two maturity classes would be highly desirable. Currently used visual separation of rapidly moving melons on a sorting belt is inadequate and error prone. No rapid and accurate detection and sorting method exists for commercial application. Rapid, accurate, and economically sound separation of honeydew melons would permit (1) exclusion of fruit so immature that it never would ripen, even if treated with ethylene; (2) separation of fruit into ripeness classes for shipment to distant and close-by markets; (3) separation of classes by need for ethylene treatment; and (4) exclusion of fruit that is already overripe.

Literature Cited

- (1) Bianco, V. V., and H. K. Pratt. 1977. Compositional changes in muskmelons during development and in response to ethylene treatment. *Journal of the American Society for Horticultural Science* 102:127-133.
- (2) California Department of Food and Agriculture. 1976. Extracts from the administrative code—Title 3 of California pertaining to rules and regulations of fruit and vegetable quality control standardization. Article 17.
- (3) Davies, R., and W. W. Boyes. 1940. Pre-storage treatment of Kelsey plums with acetylene and ethylene. Union of South Africa, Department of Agriculture and Forestry. Annual Report of the Low Temperature Research Laboratory 1938-1939, p. 31-40.
- (4) _____ and W. W. Boyes. 1940. Pre-storage treatment of Elberta peaches with acetylene. Union of South Africa, Department of Agriculture and Forestry. Annual Report of the Low Temperature Research Laboratory 1938-1939, p. 41-43.
- (5) Federal-State Market News Service. 1981. Marketing California and Arizona melons. 1980 Season. U.S. Department of Agriculture, Agricultural Marketing Service, Market News Branch, Fresno, Calif.
- (6) Harris, C. M., and R. H. Hinds, Jr. 1977. Transit refrigeration of perishables in overseas van container shipments. U.S. Department of Agriculture, Marketing Research Report No. 1071, 10 p.
- (7) Kader, A. A., W. J. Lipton, and L. L. Morris. 1973. Systems for scoring quality of harvested lettuce. *HortScience* 8:408-409.
- (8) Lipton, W. J. 1978. Chilling injury of 'Honey Dew' muskmelons: Symptoms and relation to degree of ripeness at harvest. *HortScience* 13:45-46.
- (9) _____. 1981. Duration of prestorage ethylene treatment affects quality of 'Honey Dew' melons held at chilling temperatures. *Acta Horticulturae* 116:139-149.
- (10) _____ and Y. Aharoni. 1979. Chilling injury and ripening of 'Honey Dew' muskmelons stored at 2.5° or 5°C after ethylene treatment at 20°C. *Journal of the American Society for Horticultural Science* 104:327-330.
- (11) _____ Y. Aharoni, and E. Elliston. 1979. Rates of CO₂ and ethylene production and of ripening of 'Honey Dew' muskmelons at a chilling temperature after pretreatment with ethylene. *Journal of the American Society for Horticultural Science* 104:846-849.
- (12) _____ W. K. Asai, and D. C. Fouse. 1981. Deterioration and CO₂ and ethylene production of stored mung bean sprouts. *Journal of the American Society for Horticultural Science* 106:817-820.
- (13) Maxie, E. C., F. G. Mitchell, N. F. Sommer, and others. 1974. Effect of elevated temperature on ripening of 'Bartlett', *Pyrus communis* L. *Journal of the American Society for Horticultural Science* 99:344-349.
- (14) Ogura, N., R. Hayashi, T. Ogishima, and others. 1976. Ethylene production by tomato fruits at various temperatures and effect of ethylene on the fruits. (In Japanese, English summary.) *Nippon Nogeikagaku Kaishi* 50:519-523.
- (15) Ostle, B. 1963. Statistics in research. Second edition. Iowa State University Press, Ames. 481 p.
- (16) Pratt, H. K., J. D. Goeschl, and F. W. Martin. 1977. Fruit growth and development, ripening, and the role of ethylene in the 'Honey Dew' muskmelon. *Journal of the American Society for Horticultural Science* 102:203-210.
- (17) Ramsey, G. B., and M. A. Smith. 1961. Market diseases of cabbage, cauliflower, turnips, cucumbers, melons, and related crops. U.S. Department of Agriculture, Agriculture Handbook No. 184, 49 p.

- (18) Redit, W. H. 1969. Protection of rail shipments of fruits and vegetables. U.S. Department of Agriculture, Agriculture Handbook No. 195, 98 p.
- (19) Ryall, A. L., and W. J. Lipton. 1979. Handling, transportation and storage of fruits and vegetables. Volume 1. Vegetables and Melons. Second edition. AVI Publishing Company, Westport, Conn. 587 p.
- (20) Steel, R. G. D., and J. H. Torrie. 1960. Principles and procedures of statistics. McGraw-Hill, New York. 481 p.
- (21) Wiant, J. S. 1938. Market-storage studies of Honey Dew melons and cantaloups. U.S. Department of Agriculture, Technical Bulletin No. 613, 19 p.
- (22) Yoshioka, H., Y. Ueda, and K. Ogata. 1978. Physiological studies in fruit ripening in relation to heat injury. I. Effect of elevated temperatures on ripening of banana fruit. Journal of Japanese Society Food Science Technology 25:607-611. (In Japanese with English summary and legends.)
- (23) Yu, Y., D. O. Adams, and S. F. Yang. 1980. Inhibition of ethylene biosynthesis by 2,4-dinitrophenol (DNP) and high temperature. Plant Physiology 65 (supplement):40 (abstract).

United States Department of Agriculture
Agricultural Research Service
Beltsville Agricultural Research Center-West
Beltsville, Maryland 20705

OFFICIAL BUSINESS
Penalty for Private Use, \$300



Postage and Fees Paid
U.S. Department of Agriculture
AGR-101